What could we learn
from
detailed simulations
on
a single crystal

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IPN Orsay

PARIS Collaboration Meeting Krakow, October 2009

Energy deposit GEANT 4 simulations

T. Zerguerras

Light collection LITRANI simulations

B. Genolini

PARIS Collaboration Meeting Krakow, October 2009

Geometries and materials

Materials:

- $LaBr_3$, density: 5.10 g/cm^3
- CsI density: 4.53 g/cm^3

Single $LaBr_3$:

- Box 2'' × 2'' × 2'' (I)
- Box 2'' × 2'' × 4'' (II)

PARIS Phoswich:

- $LaBr_3$ box: 2'' × 2'' × 2''
- CsI box 2'' × 2'' × 6.2''

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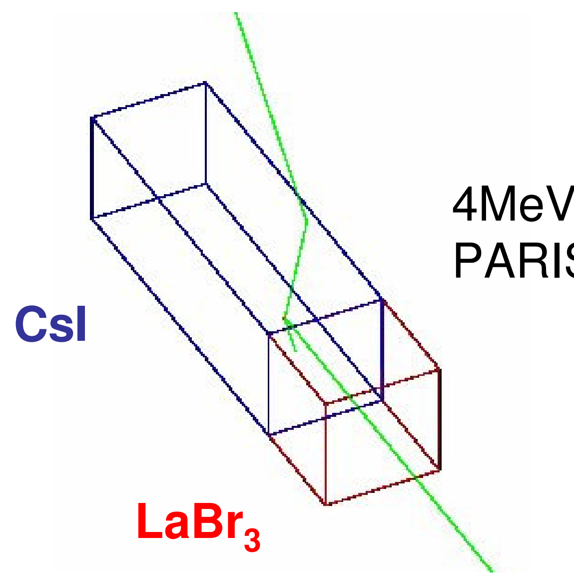
Primary event

γ on normal incidence on the center of the crystal forward face
The Z axis is the direction of the incident particle
10 000 generated events for each energy.

<u>Energies:</u>

- Single $LaBr_3$: 1, 2, 4, 6, 8, 12, 16 and 20MeV.
- PARIS Phoswich: 1, 2, 4, 6, 8, 12, 16 and 20MeV.



4MeV γ interacting in a PARIS phoswich

Physics model

GEANT 4, v9.1p03 low energy electromagnetic package, including G4EMLOW 6.2 tables (for atomic deexcitation processes, like: X-ray fluorescence, Auger emission …) .

γ physics list includes:

- **Photoelectric effect *(G4LowEnergyPhotoelectric)***
- **Compton scattering *(G4LowEnergyCompton)***
- **Rayleigh scattering *(G4LowEnergyRayleigh)***
- **Gamma conversion *(G4LowEnergyGammaConversion)***

e^- physics list includes:

- **Multiple scattering *(G4MultipleScattering)***
- **Ionisation *(G4LowEnergyIonisation)***
- **Bremsstrahlung *(G4LowEnergyBremsstrahlung)***

e^+ physics list includes:

- **Multiple scattering *(G4MultipleScattering)***
- **Ionisation *(G4eIonisation)***
- **Bremsstrahlung *(G4eBremsstrahlung)***
- **Annihilation *(G4eplusAnnihilation)***

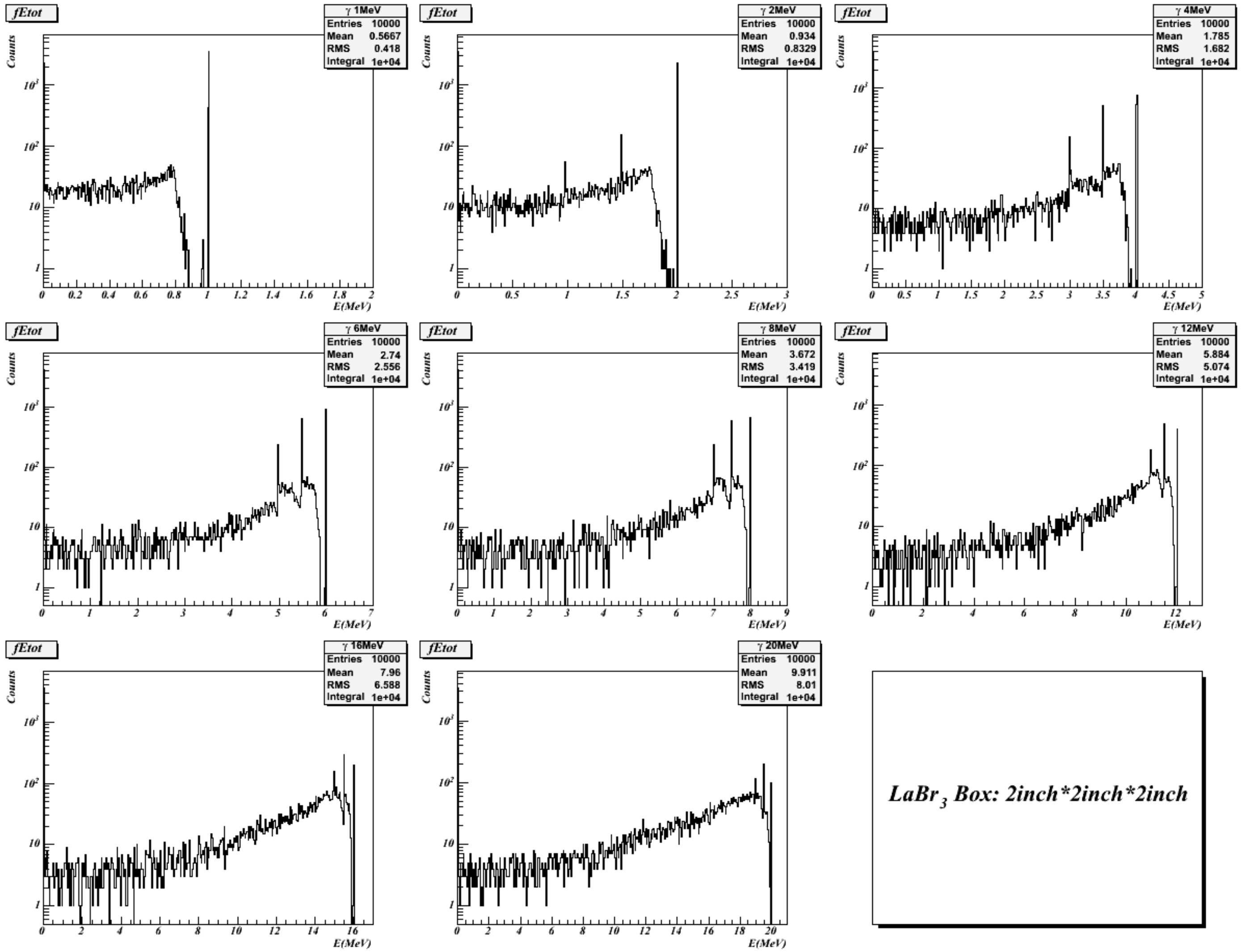
Informations from GEANT4 simulations

- Crystal energy response (no energy resolution distribution included)
- γ interaction probability
- Hits distribution inside crystals

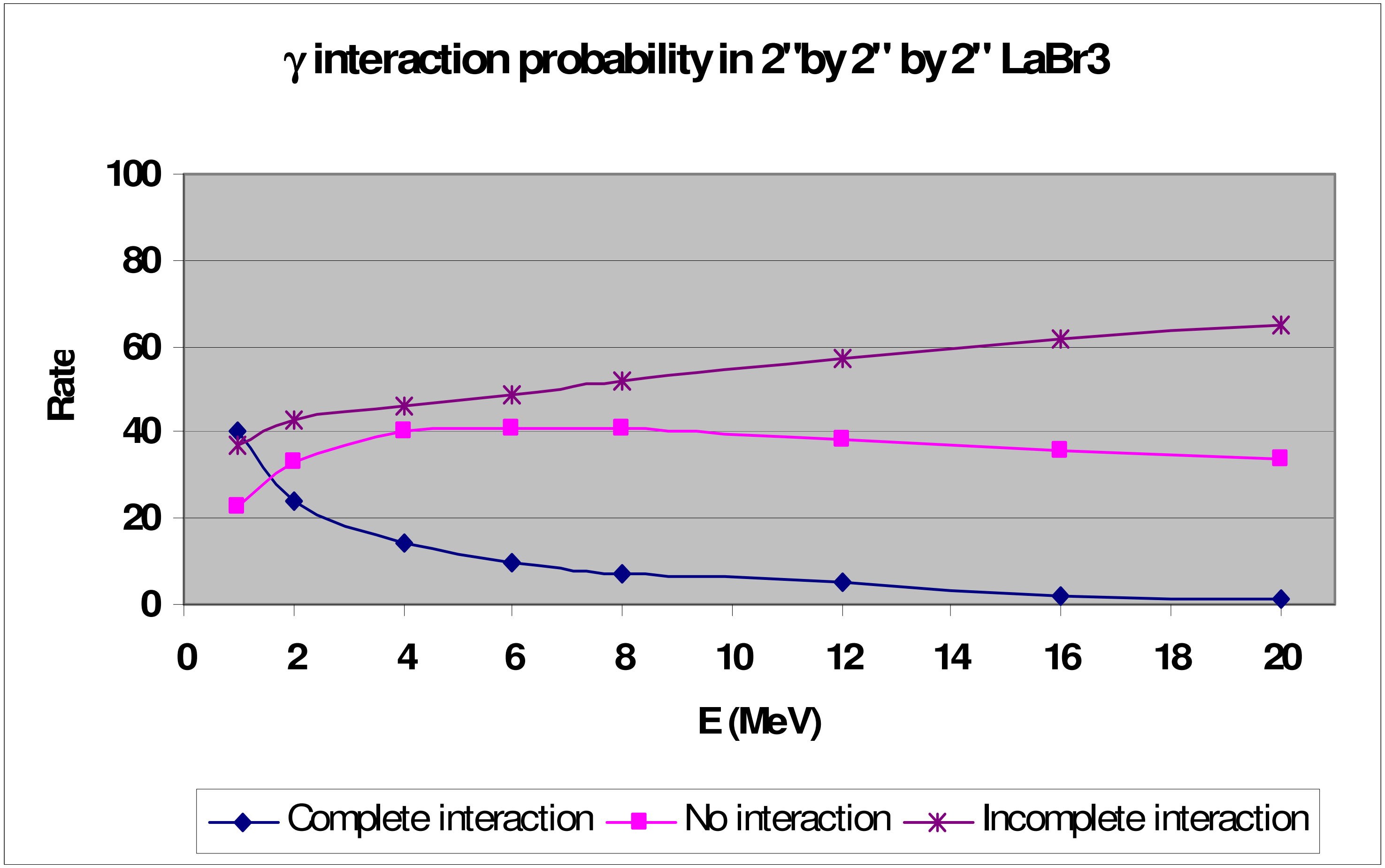
  → Points for scintillation light emission injected in LITRANI for light response calculations (see B. Genolini work).

Single $LaBr_3$ crystal

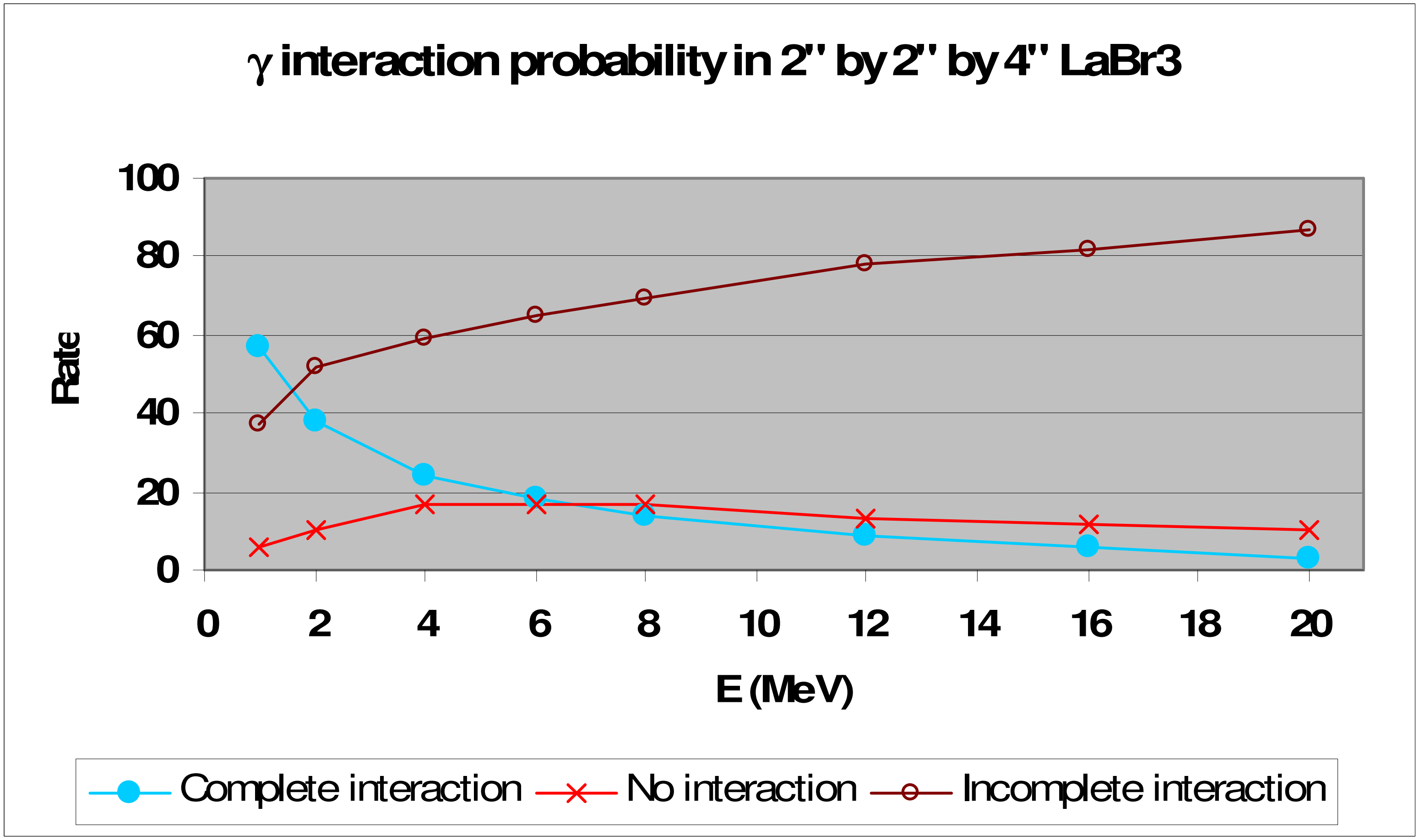
2’’ × 2’’ × 2’’ crystal energy response



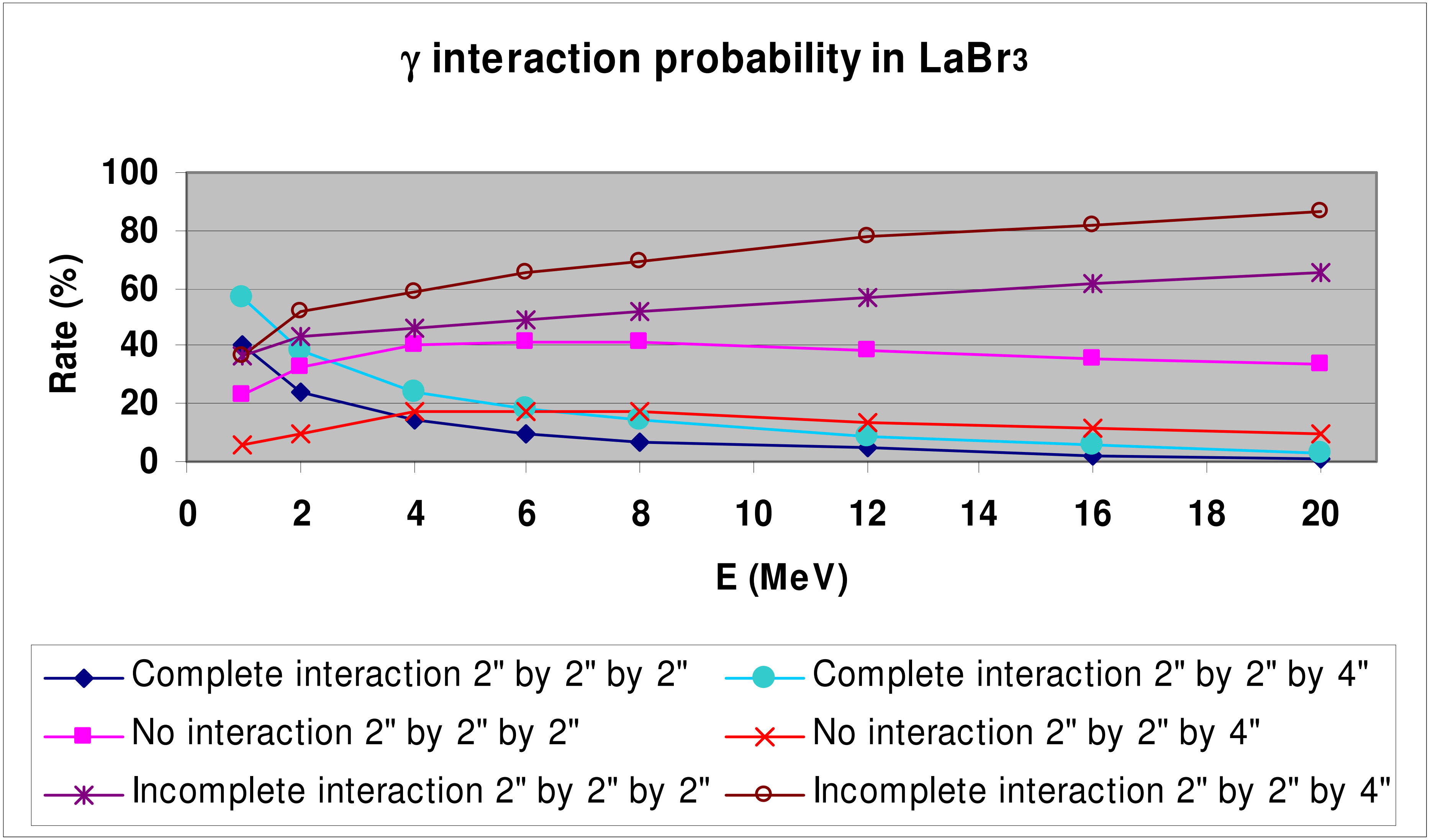
Interaction probability in 2'' by 2'' by 2'' $LaBr_3$



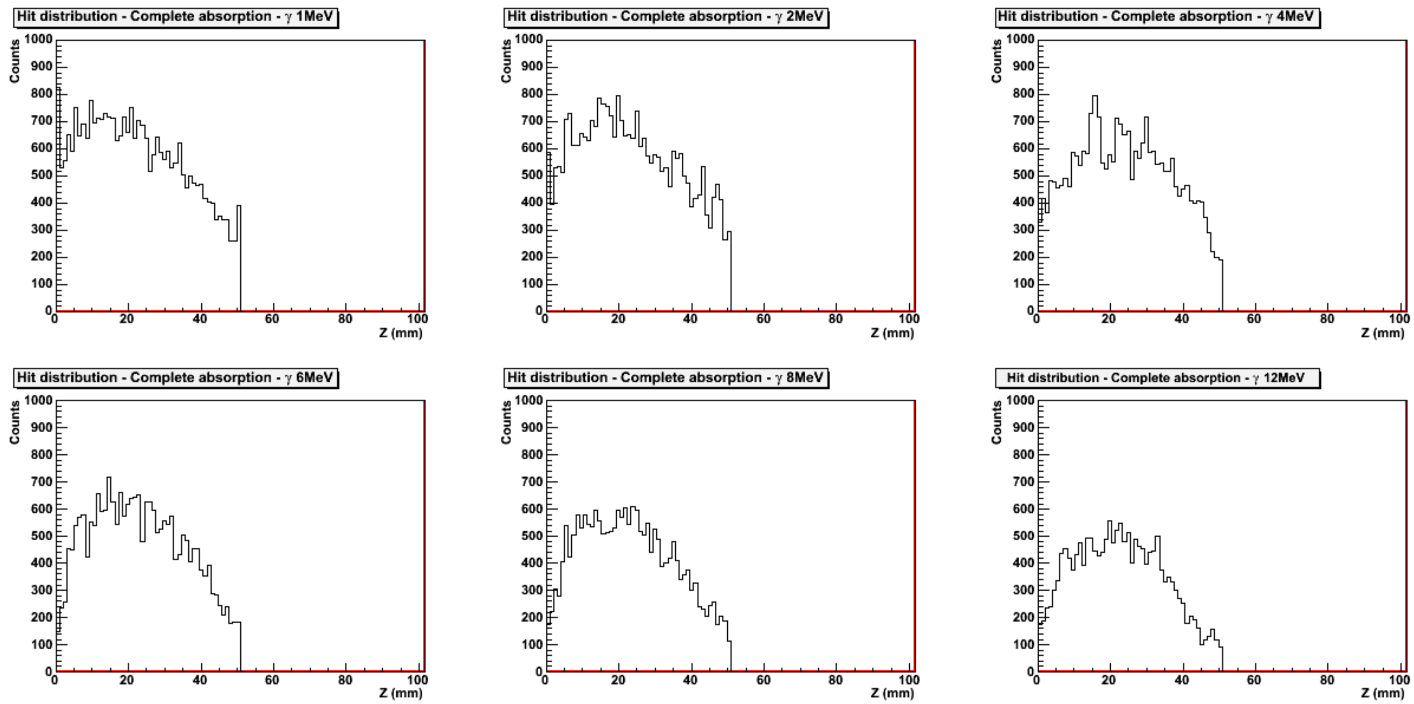
Interaction probability in 2’’ by 2’’ by 4’’ $LaBr_3$

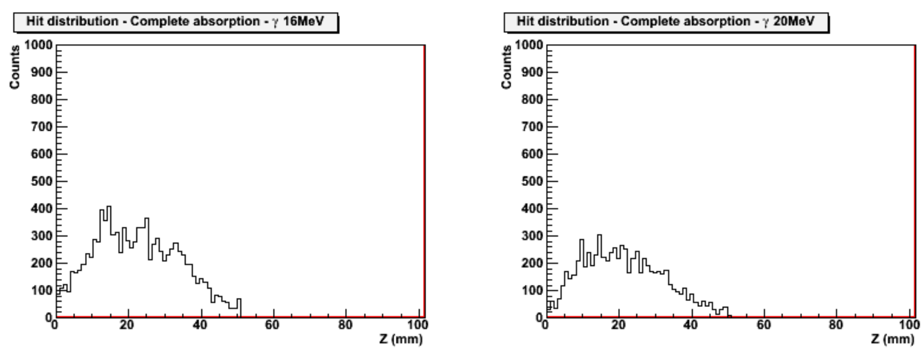


Interaction probability



Complete absorption, Z distrib. of dE/dz (I)





$LaBr_3$

$LaBr_3$ Box 2inch*2inch*2inch

2''x 2'' **x 2''**

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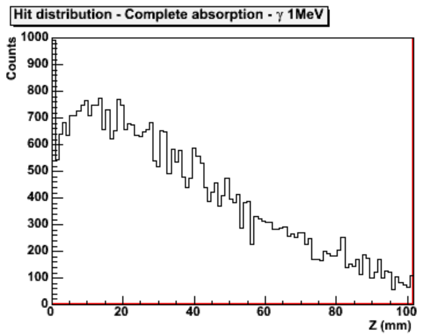
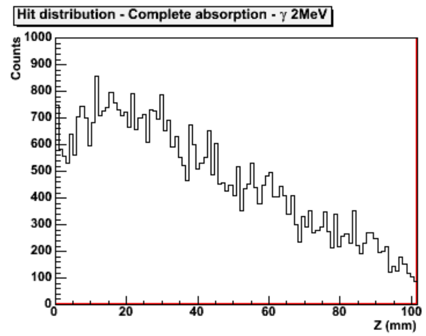
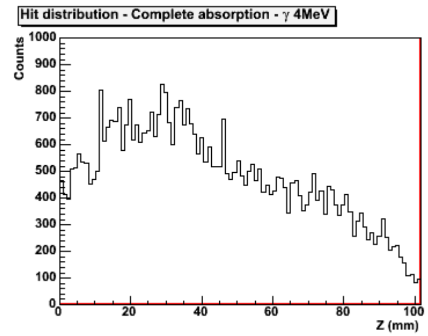
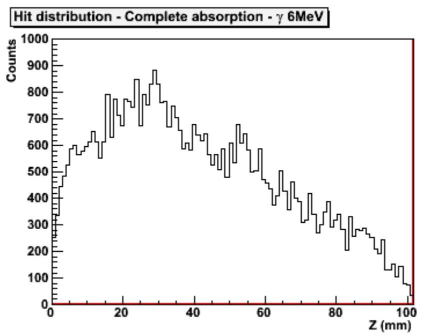
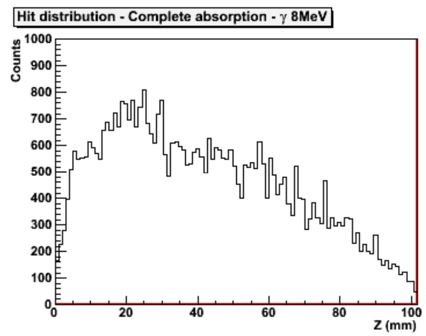
Complete absorption, Z distrib. of dE/dz (II)

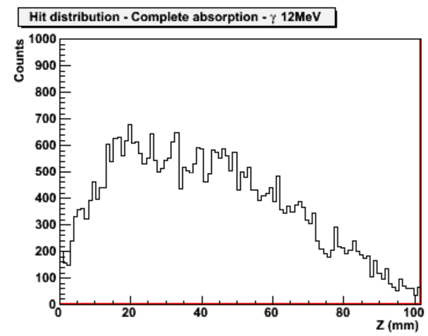


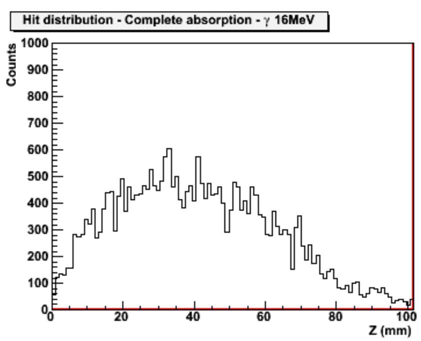


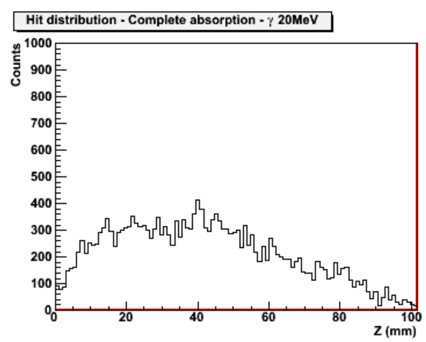












$LaBr_3$

$LaBr_3$ Box 2inch*2inch*4inch

2’’x 2’’ **x 4’’**

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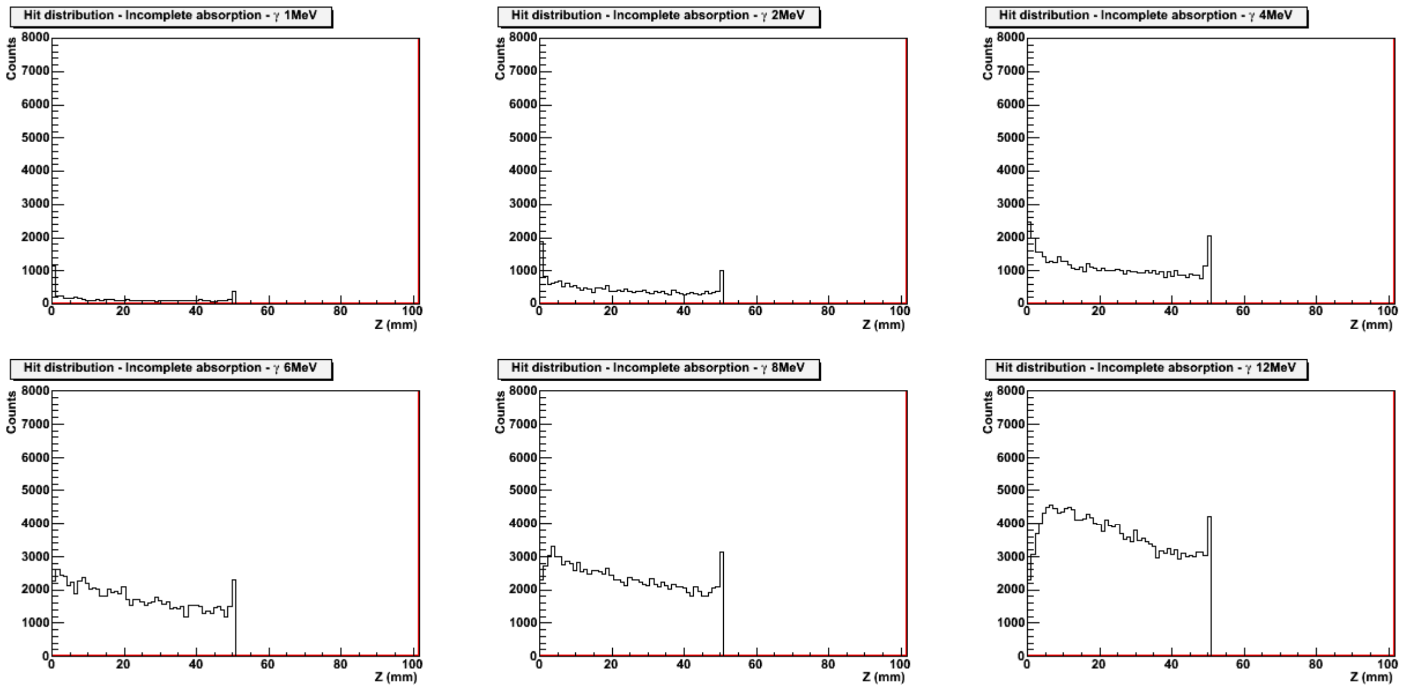
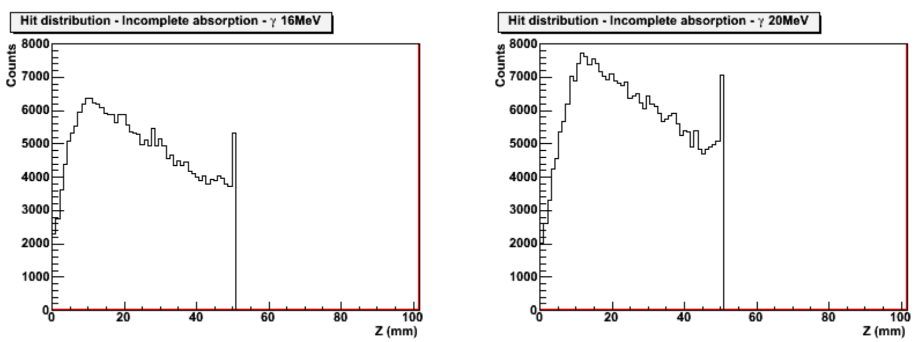
Incomplete absorption, Z distrib. of dE/dz (I)





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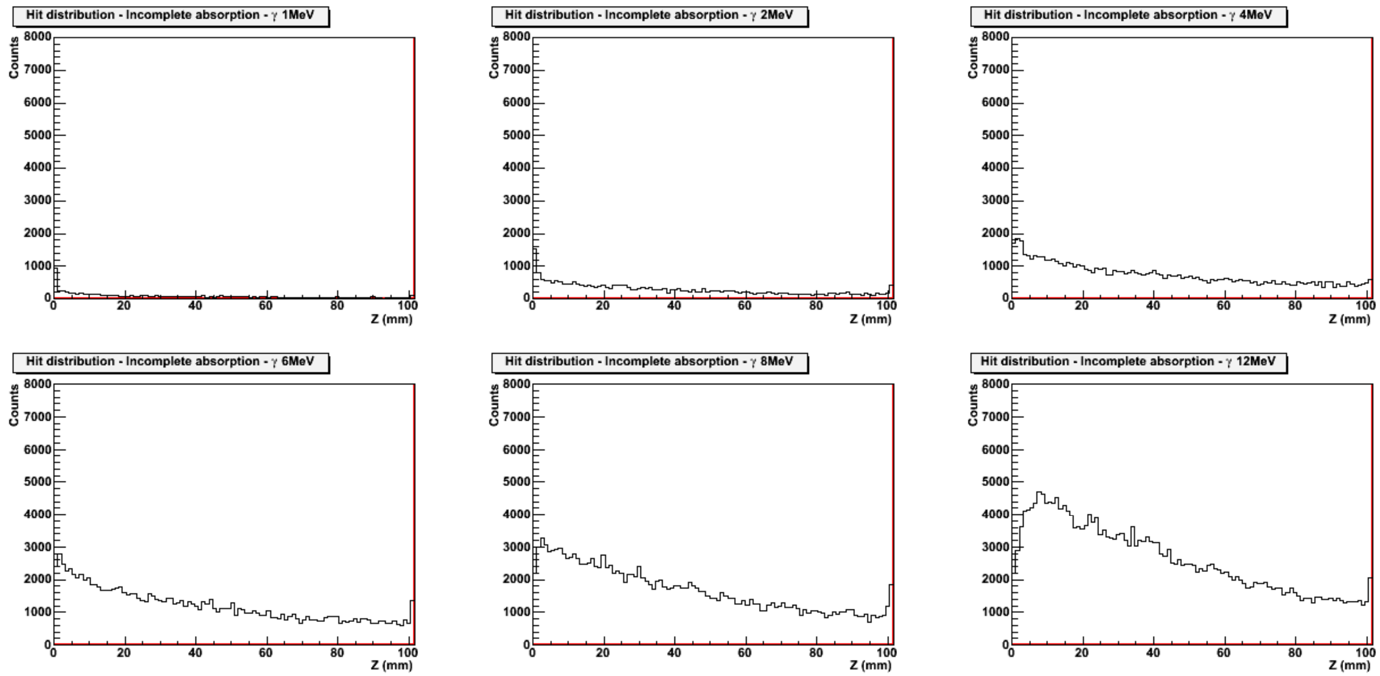

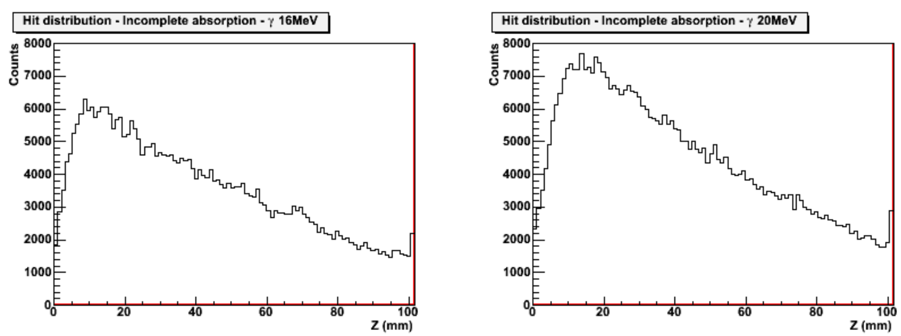

$LaBr_3$

$LaBr_3$ Box 2inch*2inch*4inch

2''x 2'' **x 4''**

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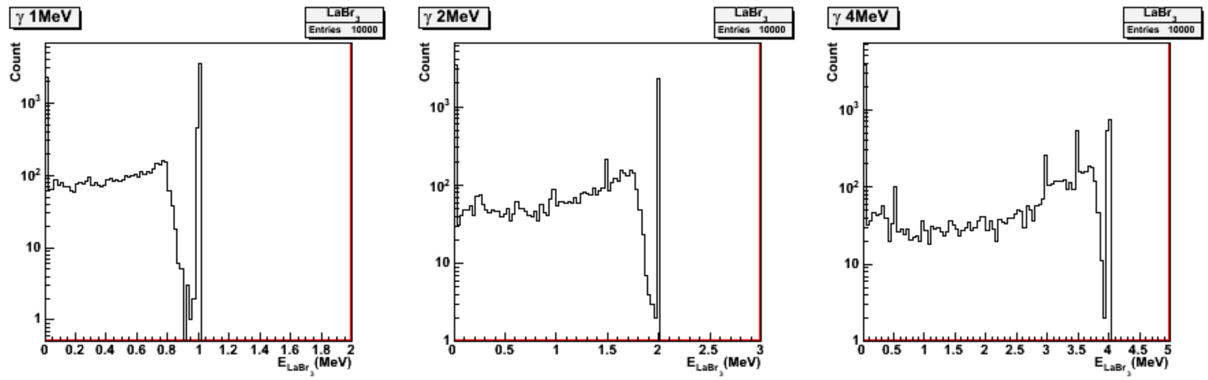
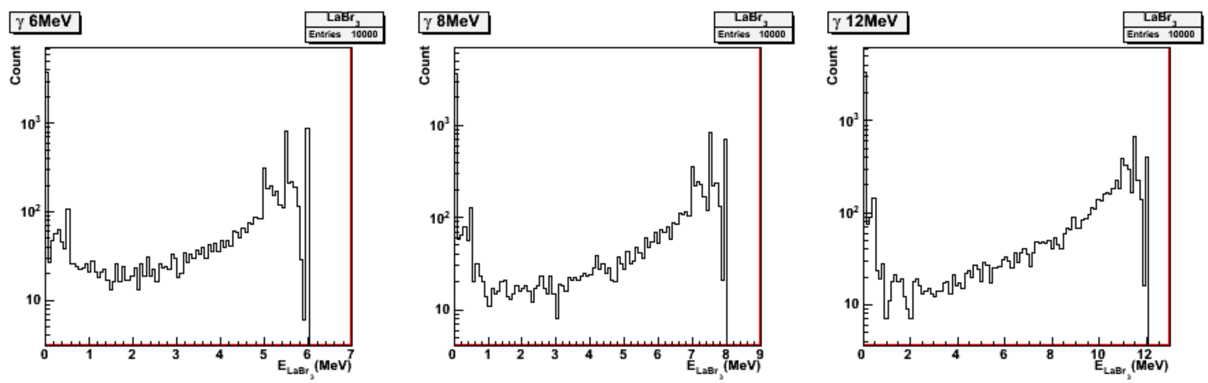
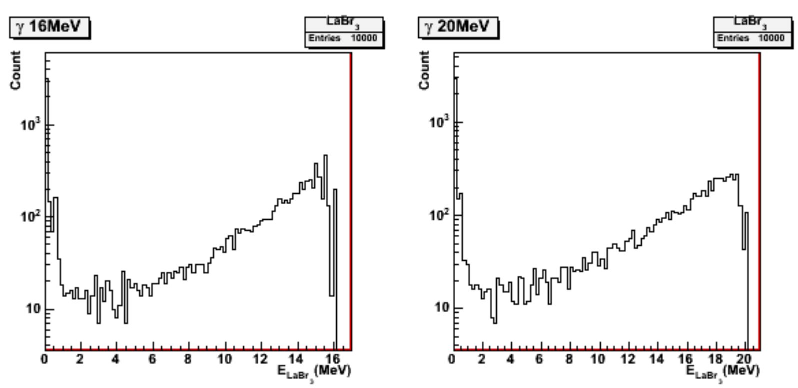
PARIS Phoswich

$LaBr_3$ energy response





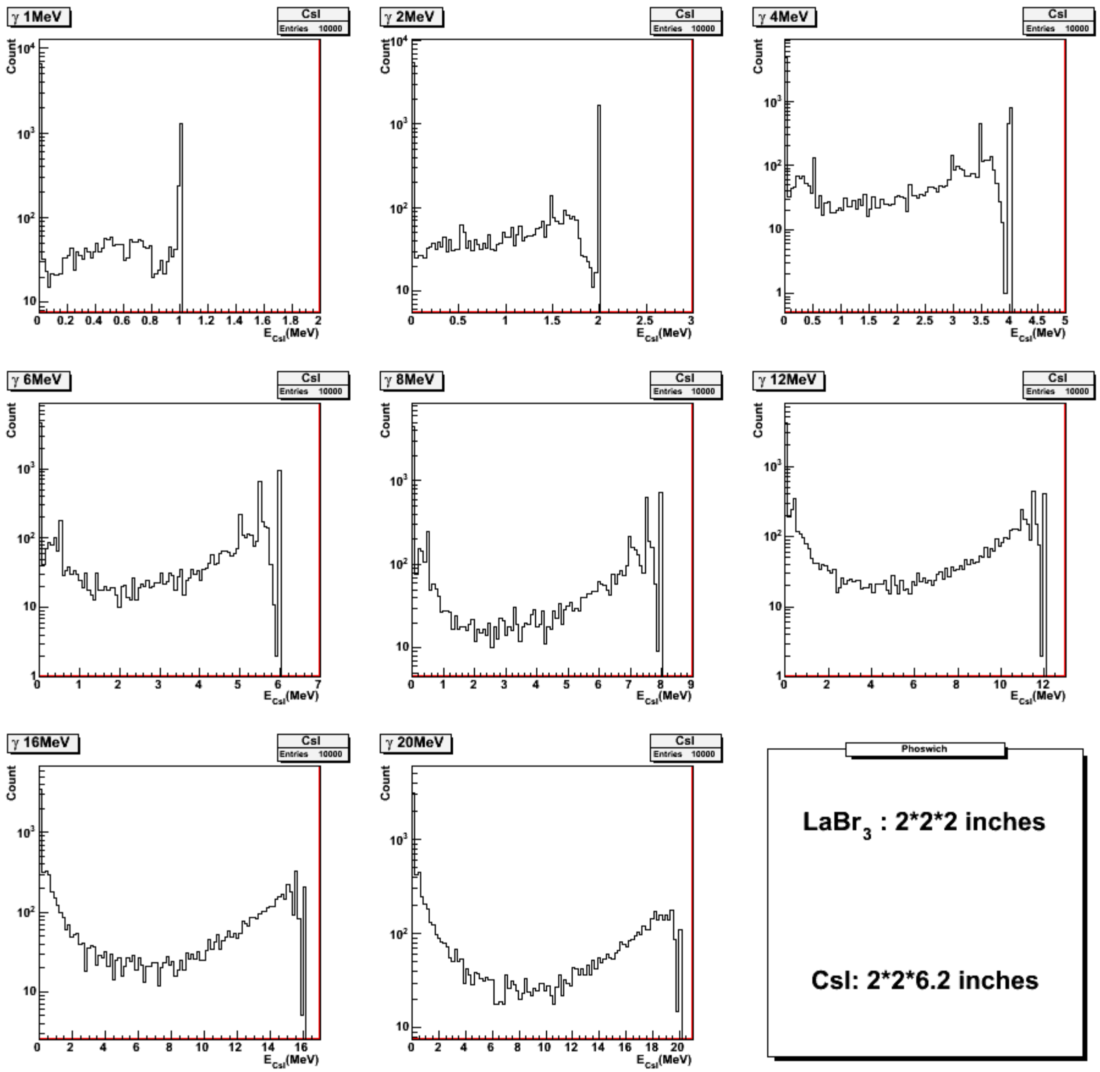


Phoswich

$LaBr_3$: 2*2*2 inches

CsI: 2*2*6.2 inches

CsI energy response



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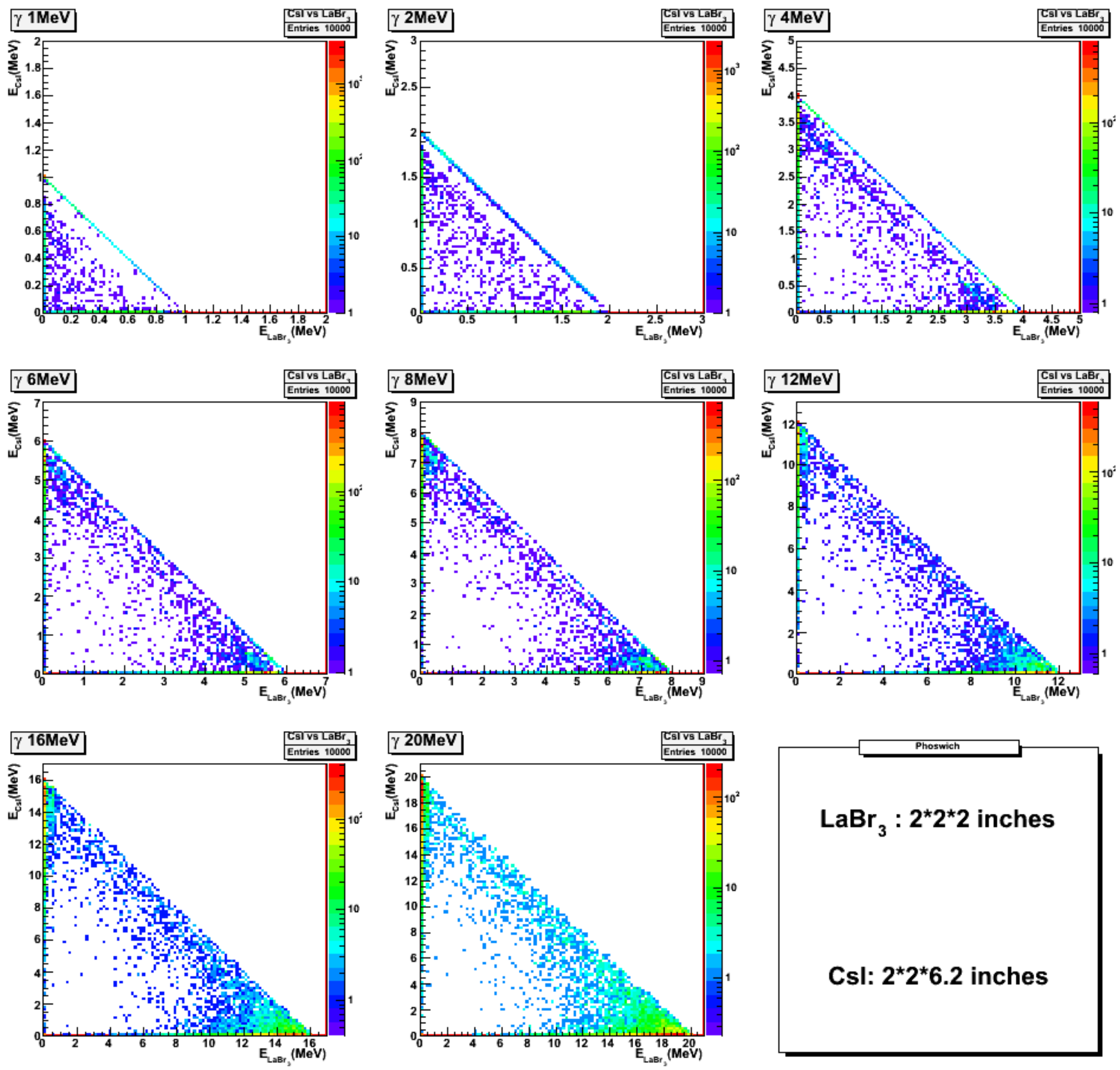
$LaBr_3$- CsI energy correlation



Events on straight line with Slope equal to 1

→ **Complete Absorption in Phoswich**

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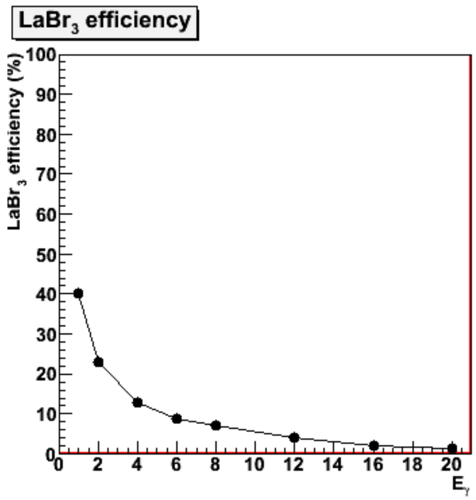
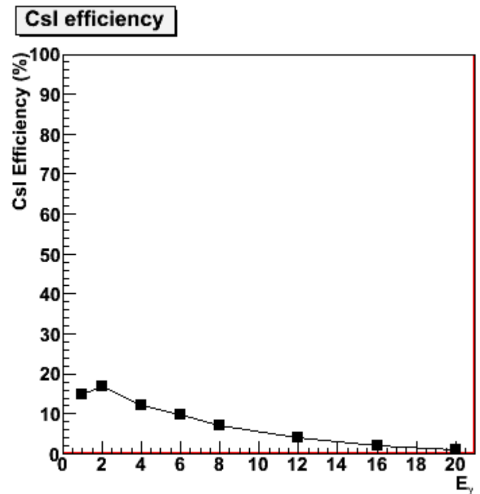
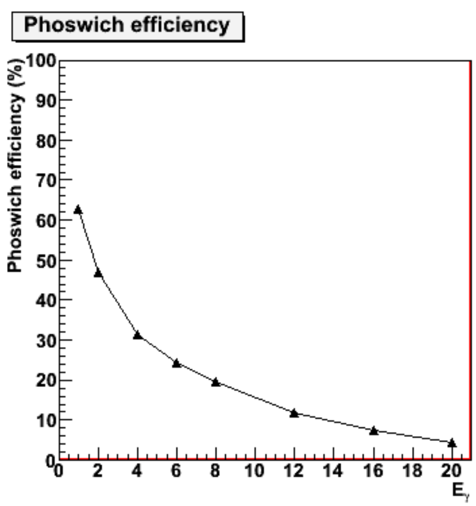
Efficiencies







Phoswich

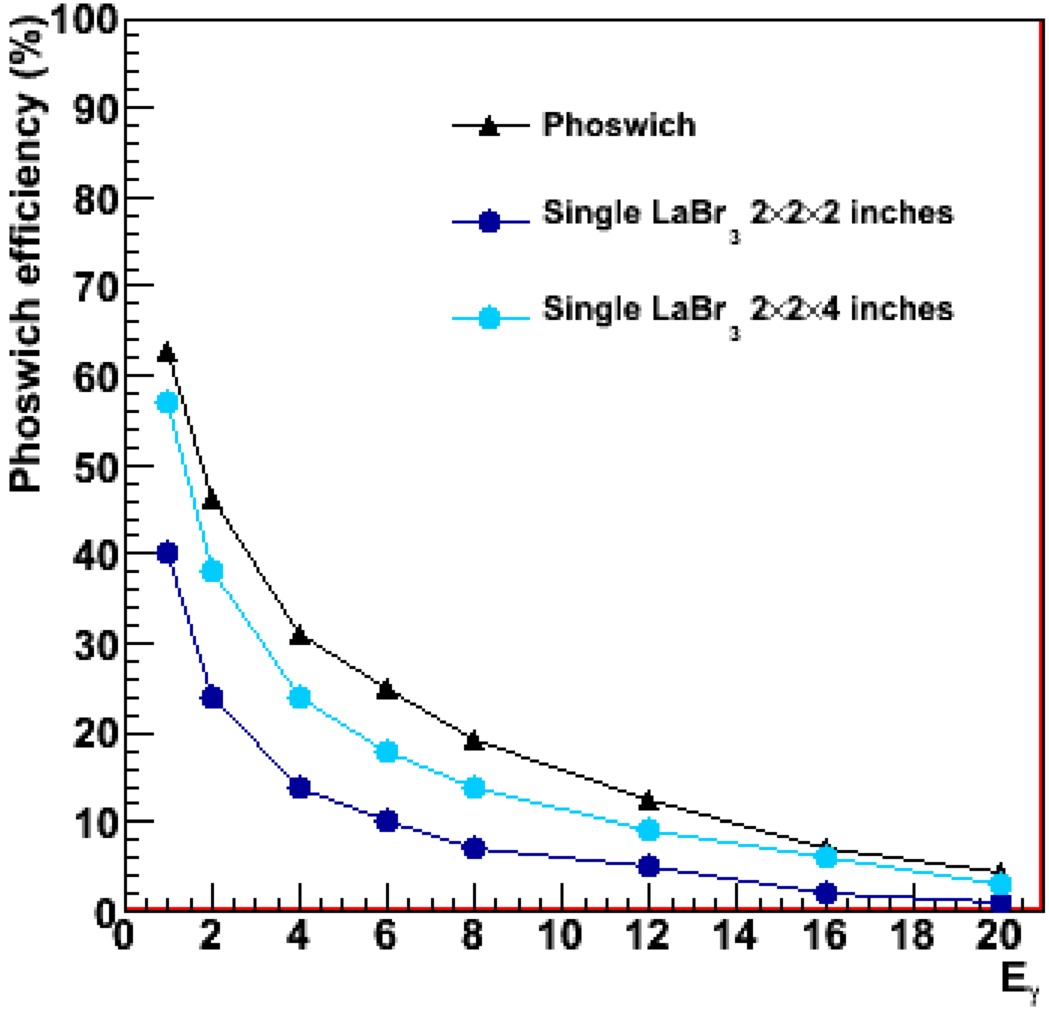
$LaBr_3$: 2*2*2 inches

CsI: 2*2*6.2 inches

Events where more than 99% of the incident γ energy is measured

Efficiencies

Events where more than 99% of the incident γ energy is measured



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What is Litrani ?

LITRANI stands for LIght TRansmission in ANIsotropic media.

- General purpose Monte-Carlo program to simulate the propagation of optical photons
- ROOT library
- Developped at CEA, Saclay, France for GLAST and the CMS calorimeter (http://gentit.home.cern.ch/gentit/litrani)
- Classes and data library from measured materials :
  - Scintillators: $PbWO_4$, CsI(Tl)
  - Revetments: Aluminum,Tyvek, VM2000
  - Detectors: PMT (XP2020), APD
  - Surface state: depolished, thin slice of air
- Extendable library (Photocathode sensitivity, scintillator emission spectrum, etc.)

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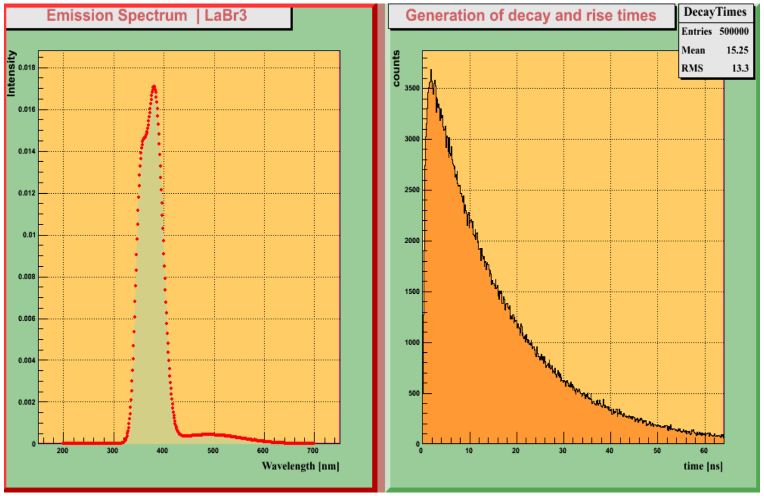
What calculates Litrani?

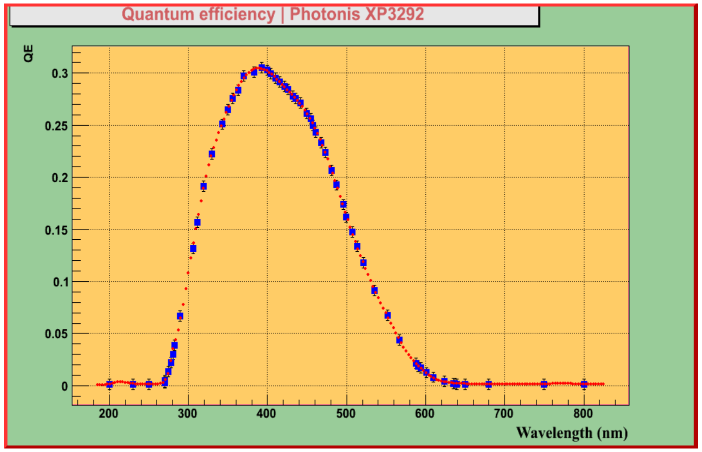
- Generate light according to the models given in input
- Photon trajectory
- Automated reports:
  - Distance travelled by photons
  - Number of photons absorbed in material
  - Number of photons hitting a face
  - Number of photons traversing a face
  - Number of hits per face

Simulation steps

- Model of the LaBr3 scintillator
  - Determine the emission peaks from Gaussian fits
  - Decay time: defined according to the data sheet
  - Absorption Length: not found – took 5 m
  - Wrapped with aluminum
  - Light yield: 63 photons / keV (Saint-Gobain data)
- Photocathode:
  - Quantum efficiency: data from Photonis XP3292 (30 % QE at max)
  - segmentation: 5×5 subfaces
  - N.B.: photons not transformed are lost. The photons reflected by the aluminum and the first dynode of the PMT input are also lost.
- Event generation
  - Gamma interaction simulated by T. Zerguerras with Geant 4
  - Light emission: isotropic emission generated with the specified decay, from the calculated energy deposit. The possible crystal non linearity is introduced at this step.
- Run Litrani
  - Run on a reduced set of events (250 to 1000 to get the resolution and the histogram, 25 to estimate the number of photoelectrons)
  - Automated reports: information where the losses occur.
  - The program tracks the photons: get the information on sub-faces of the photocathode.



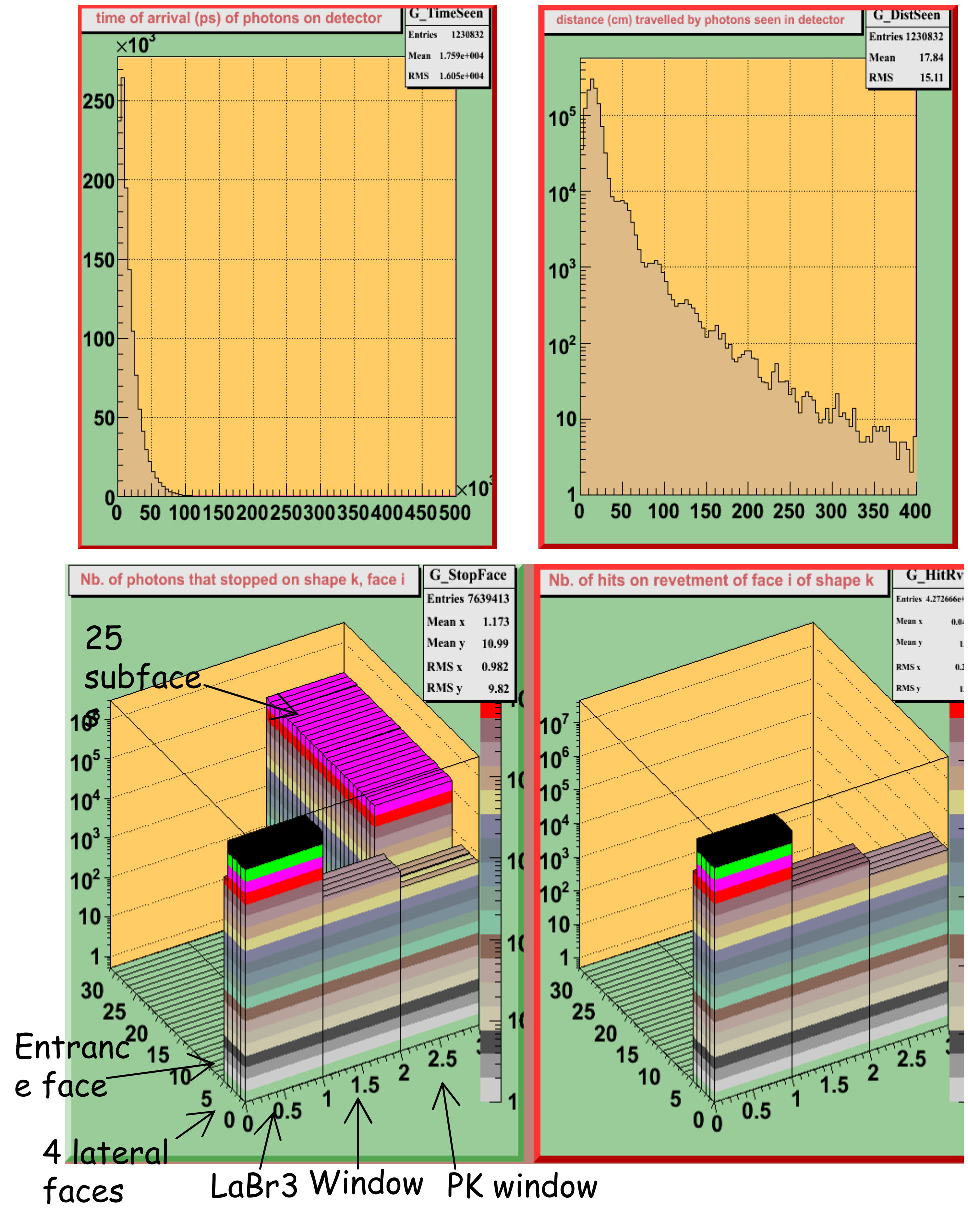
LaBr3 light emission



QE Photocathode XP 3292

Examples of reports

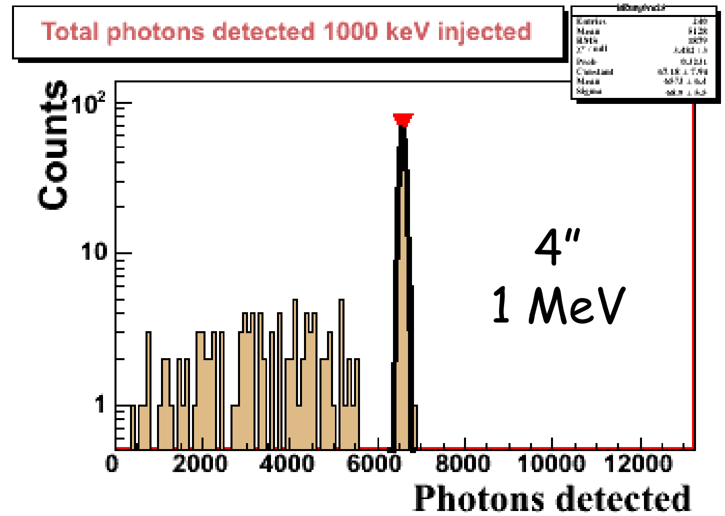
```
Nb. of photons generated     : 11773479
Lost for abnormal reasons    : 0
Lost because abs. length 0   : 0
Eff. nb. of gen. photons     : 11773479
Nb. of photons seen          : 1230832
Efficiency                   :   0.104543
   error                     :  +/-9.42312e-005
Lost for any reason          : 10542647
Lost in materials            : 4134064
Lost before wrapping         : 0
Lost in wrapping             : 3258339
Lost leaving setup           : 0
Lost because seen too late   : 2
Lost b. too few e- in APD    : 0
Lost b. acceptance angle     : 0
Lost b. quantum efficiency   : 3150242
```



- Configuration: 4", 1 MeV
- Calculated with 250 events

Preliminary results

Front face: 2"×2"	**1 MeV**	**8 MeV**
4"	**6 573 phe** (250 evts)	**47 075 phe** (25 evts)
2"	**6 377 phe** (250 evts)	**47 275 phe** (25 evts)
Phoswich 2" LaBr3 6" CsI(Tl)	LaBr3 **5 847 phe** (50 evts)	LaBr3 **41 277 phe** (50 evts)



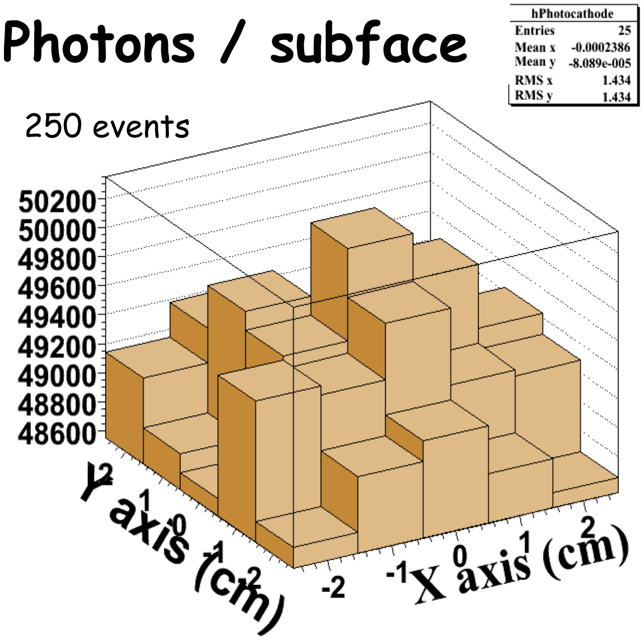
- At 1 MeV : 6500 phe ⇒ 3.1 % FWHM
  (with 10 % ENF and no contribution of the scintillator intrinsic resolution)
  (Measurement: 2.7 % FWHM)
- At 8 MeV : 47 000 phe ⇒ 1.1 % FWHM
  (47 000 instead of 52000. Fit on a very low number of events)
- With the Phoswich, LaBr3 only:
  5 800 phe ⇒ 3.2 % FWHM and 41 000 phe ⇒ 1.2 % FWHM

The results are sensitive to the wrapping (here, Aluminum)

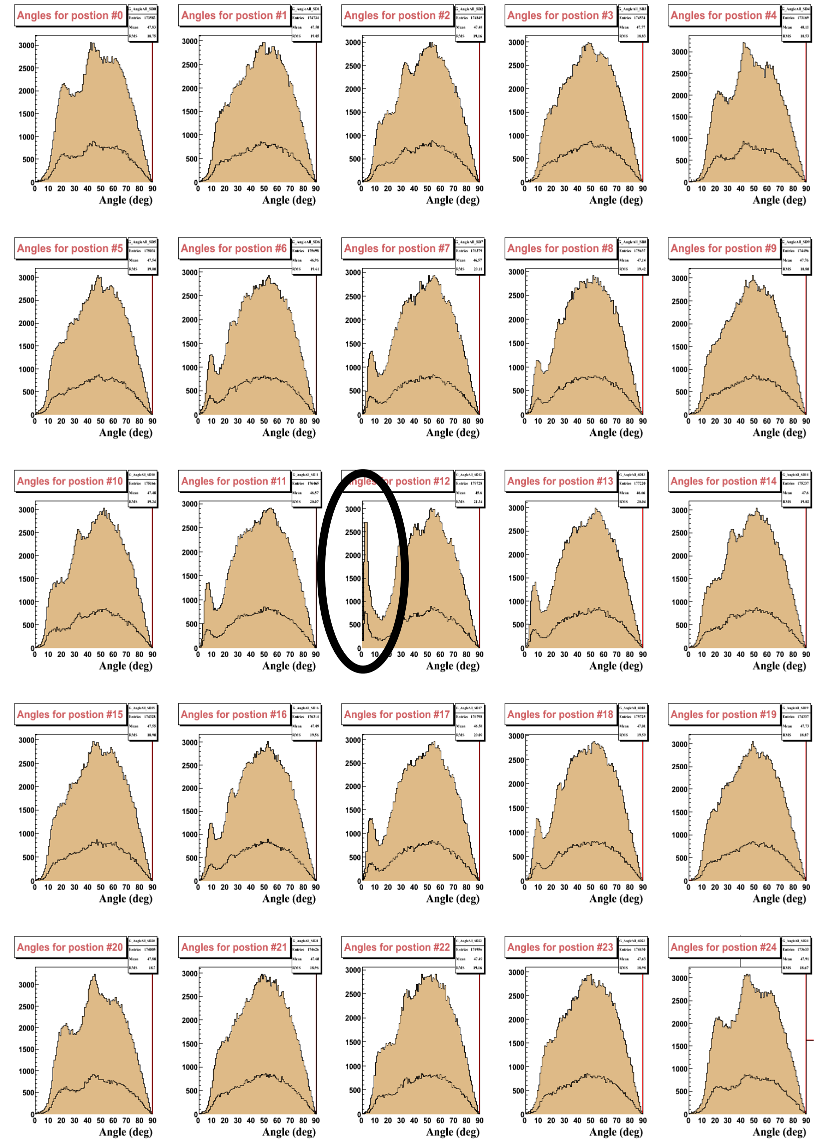
Photocathode study (4" scint, 1 MeV)

Photons / subface

250 events



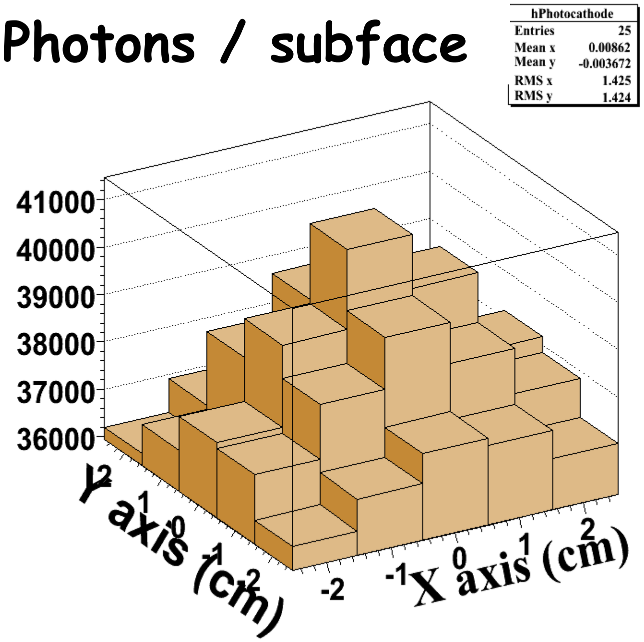
- Charge distribution on the cathode: less than 5 % variation.
- Distribution of angles of arriving photons (0 to 90°, 0° = perpendicular to the surface)
- Negligible contribution of the direct light
- Majority : average ≈ 48°



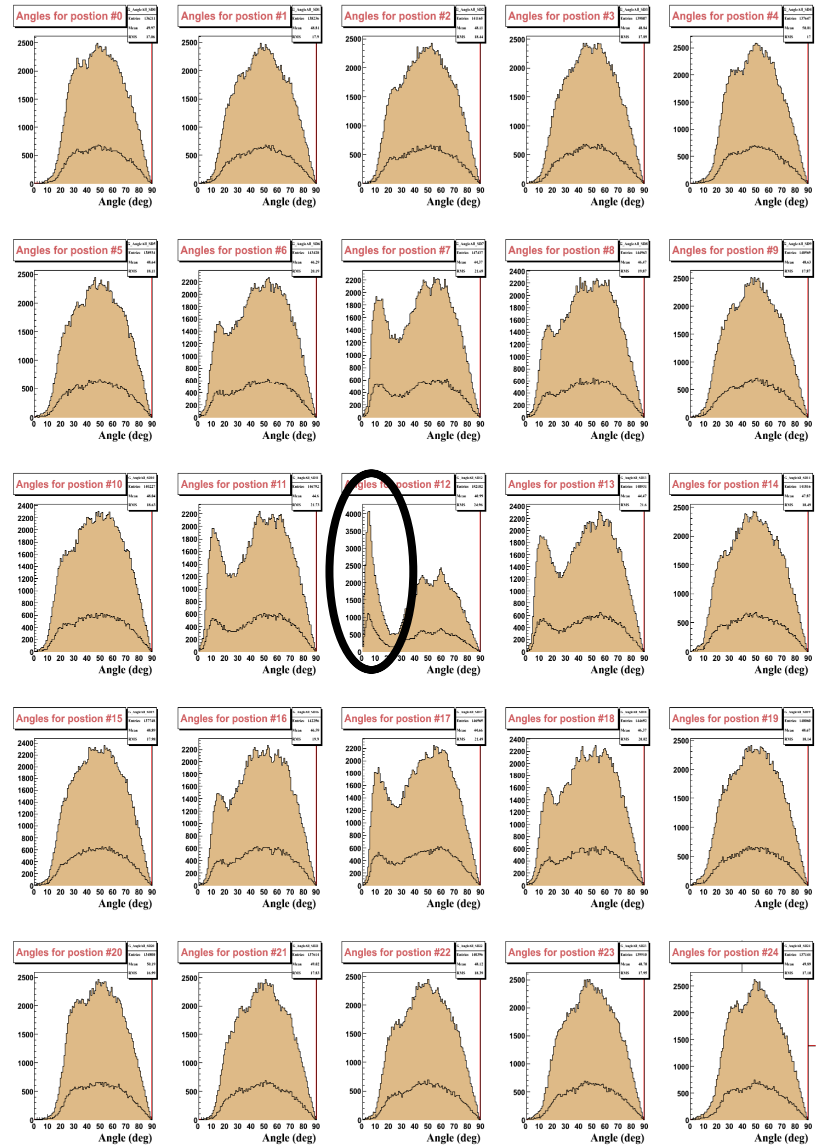
Angular distribution

Photocathode study (2" scint, 1 MeV)

Photons / subface



- Greater proportion of direct light
- Smaller number of total photons (due to a lower efficiency)



Angular distribution

Conclusions

- Good agreement with measurements
- Poor capacity to localize
- Possibility to understand where the light losses occur
- Next simulations:
  - More statistics
  - Phoswich with better model and energy deposit in the CsI(Na)

Back up

Energy Resolution you can obtain with Scintillators

With a PMT:

$$R^2 = R_S^2 + R_M^2$$

The contribution of the noise is negligible

R: Overall resolution

R_S: Intrinsic scintillator resolution

R_M: Statistical resolution

$$R_M = 2.35\sqrt{\frac{1+v(M)}{N}}$$

v(M): variance of the PMT gain (~0,1)

N: Number of photoelectrons

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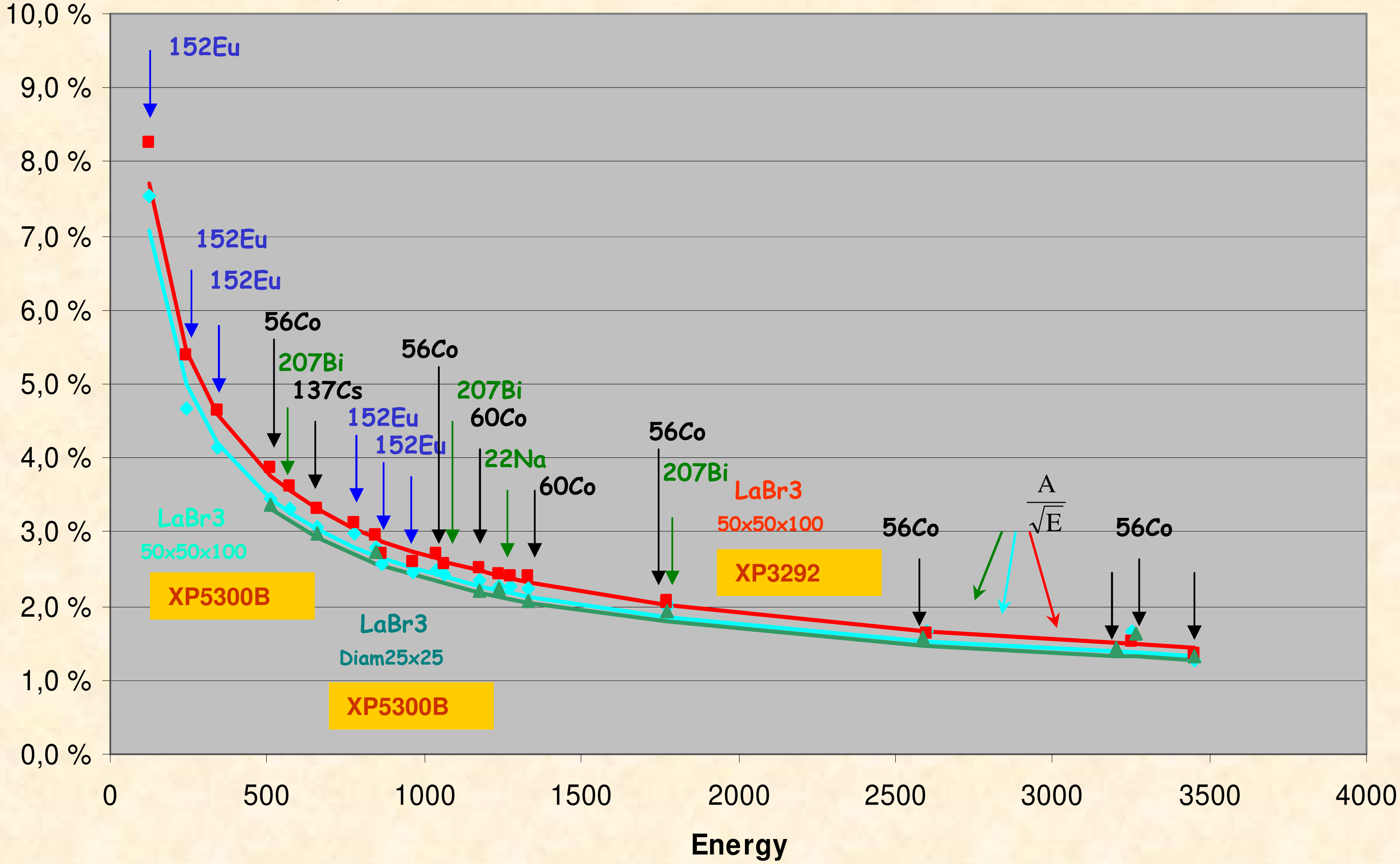
Energy Resolution (FWHM) for $LaBr_3$

50x50x100+XP3292: 12,4 µA/lmF R% FWHM 662keV=3,3%
50x50x100+XP5300B: 14,6 µA/lmF R% FWHM 662keV=3,0%
diam25x25+XP5300B: 14,6 µA/lmF R% FWHM 662keV=2,9%
diam25x25+XP5301: 16,7 µA/lmF R% FWHM 662keV=2,7%

Sensibilité de la photocathode est un paramètre essentiel pour la résolution



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